Land Disposal of Sewage Sludge

Volume VII

Research Report No. 98

Research Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality

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This report is a summary of University of Guelph Volume VII report and does not include 124 tables contained in the original report.

by

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ABSTRACT

This report is a summary of results obtained from the sixth year of a nine-year research program to determine maximum rates of sewage sludge application which can be used on agricultural soil without contaminating subsurface or surface waters. Two sets of experiments are described.

The first concerns field rate and source studies on the effects of treating bromegrass and corn with sludges resulting from treatment of sewage for phosphorous removal with calcium hydroxide, ferric chloride and aluminum sulphate. The effects on crop yield, plant available phosphorus, and the uptake of heavy metal ions by crops are reported and discussed.

The second was a greenhouse experiment on the growth of ryegrass treated with six fluid sludges selected for their high metal content. Crop growth, and nutrient and metal-ion uptake were studied.

In the field rate and source studies the bromegrass and corn yields were slightly higher with sludge than with ammonium nitrate application. Plant available phosphorous was increased markedly by sludge application. Heavy metal ion concentrations in plant tissue were generally increased by sludge application, while the metal concentration in corn grain was little affected.

The metal concentrations in ryegrass in the greenhouse experiments frequently did not correspond to the amounts of metals added. This was interpreted as indicating that metals in different sludges differ in their availability either because they are in different chemical form or because their uptake is influenced by other factors which differ from one sludge to another.

RÉSUMÉ

Le présent rapport fait le bilan des six premières années d'un programme de recherche échelonné sur neuf ans. Ce programme vise à déterminer le taux maximal d'épandage de boues résiduaires n'entraînant aucune contamination des eaux superficielles ou souterraines pour les sols agricoles. Deux séries d'expériences sont décrites.

Le première consiste à mesurer, sur les champs de maïs et de brome, les effets de l'épandage des boues obtenues de la déphosphatation par l'hydroxyde de calcium, le chlorure ferrique et le sulfate d'aluminum. A la suite de ces expériences, on a évalué le rendement des récoltes, la quantité de phosphore assimilable par les plantes et l'absorption, par celles-ci, des métaux lourds.

Le seconde série portait sur la croissance en serre de l'ivraie de Perse traitée par six boues liquides choisies pour leur forte teneur métallifère. On a étudié sa croissance et son absorption de substances nutritives et d'ions métalliques.

L'épandage de boues s'est révélé plus efficace que l'addition de nitrate d'ammonium pour les récoltes de brome et de maïs. Ce procédé accroît la quantité de phosphore assimilable par les plantes et la teneur en ions métalliques lourds des tissues végétaux. La teneur métallifère des grains de maïs ne semble cependant pas avoir subi de changements.

En serre, la teneur métallifère de l'ivraie ne correspond que rarement aux quantités de métaux ajoutées. Selon le type de boues, les métaux sont absorbés à des degrés divers. Ces faits sont imputables, soit aux diverses formes chimiques qu'empruntent les métaux, soit à leur absorption qui, une fois de plus, variaient d'une boue à l'autre.

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1 INTRODUCTION

The work summarized* in this report represents the sixth year of a nine-year research program on land disposal of sewage sludge. It was carried out by the Department of Land Resource Science at the University of Guelph, under funding provided by the Ontario Provincial Lottery Trust Fund through the Ontario Ministry of the Environment, during the period April 1, 1978 to March 31, 1979. Previous work under the project has been published as Land Disposal of Sewage Sludge, Canada-Ontario Agreement Research Reports listed in the bibliography of this report.

The objective of this continuing research is to determine maximum rates of sewage-sludge application which can be used on agricultural soil without either contaminating subsurface water with nitrates or surface waters with elements pathogenic to humans or animals, and without reducing the yield or quality of the crops produced.

Field and source studies on the effects of treating bromegrass and corn with sludges resulting from the treatment of sewage for phosphorus removal with calcium hydroxide, ferric chloride and aluminum sulphate. Greenhouse experiments on the growth of ryegrass treated with six different fluid sludges selected for their high metal ion content were also conducted. The effects of sludge applications on crop yield, and on nutrient and heavy metal ion uptakes were measured.

Of increasing interest as the program progresses is the study of the changes (or lack of them) in metal ion and nutrient uptake from year-to-year and crop-to-crop. Some trends in metal uptake are emerging and these are discussed briefly in the following chapters.

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* This summary is based on extensive data tabulated in the original report. These data may be obtained from the Ministry of the Environment, Pollution Control Branch, Development and Research group, Provincial Lottery Trust Fund Files, Box 213, Rexdale, Toronto, Ontario M9W 5L1

2 FIELD RATE AND SOURCE EXPERIMENTS

2.1 Introduction

Experiments have been in progress since 1973 on two soils, a Conestoga loam at the Elora Research Station and a Caledon loamy sand at the Cambridge (Hespeler) Research Station. At the Elora Research Station one experiment is in progress on a Conestoga loam with corn (*Zea mays* L.) as the crop and one with bromegrass (*Bromis inermis Leyess*). Only corn is being grown on the Caledon loamy sand at the Cambridge site.

The sources of nitrogen used in these trials have been ammonium nitrate and anaerobically digested sewage sludges resulting from treatment of sewage for phosphorous removal with calcium hydroxide, aluminum sulphate and ferric chloride. In 1978, however, the calcium hydroxide treated sewage sludge used was a raw sludge. This occurred because in 1977 the Midland sewage treatment plant, which had been the source of the calcium sludge in 1976 and 1977, switched to using ferric salts to remove phosphorus. The Caledonia sewage treatment plant thus became the most convenient source of calcium sludge, even though the sludge was not anaerobically digested. This sludge had a high pH (9 to 10), and consequently was not applied in the bromegrass trial. This resulted in one set of treatments in which calcium sludge had been applied in all previous years but none applied in 1978.

The rates of nitrogen application each year from ammonium nitrate were: 0, 100, 200 and 400 kg N/ha. The rates from each of the three sewage sludges were: 200, 400, 800 and 1600 kg N/ha.

In total, four nitrogen sources, four rates of application per source and three replications were used, resulting in a total of 48 plots for each trial. The corn plot size was 4.57 x 7.62 m (15' x 25'), and the bromegrass plot size was 2.44 x 6.09 m (8' x 20').

The weather in the summer of 1978 was atypical in that precipitation during June, July and August was approximately half the 30-year average expected for the area. This resulted in generally lower crop yields than had been experienced in previous years.

2.2 Past and Present Experimental Details

2.2.1 Bromegrass, Elora

The experimental plots were laid out on an established stand of bromegrass at the Elora Research Station on Conestoga loam in the spring of 1973. Potassium, in the form of potassium chloride, was broadcast on all plots at the rate of 47 kg K/ha in the spring of 1973, 90 kg K/ha each year in the springs of 1974 to 1977, and 100 kg K/ha in the spring of 1978. Forty kg P/ha, as 46% superphosphate, was broadcast on plots that did not receive sludge in the spring of each year from 1973 to 1977, inclusive. No phosphate was applied in 1978. Annual nitrogen rates for the bromegrass were divided into three equal applications for both ammonium nitrate and sewage sludges.

In 1978, the first cutting made up a large portion of the total bromegrass yield for the season, approximately 70%, while in previous years the first cut made up about 60% of the total yield. This is attributed to the drought in late June, July and August in 1978 which drastically reduced the yields in the second and third cuttings.

The yields of bromegrass obtained from all rates of ammonium nitrate and sludge additions were measured. In addition, analyses for the following elements were carried out.

Nitrogen (both total and nitrate-nitrogen) - in plant tissues
Phosphorus - in both plant tissues and soil (sodium bicarbonate extractable P)
Potassium - in both plant tissues and soil (ammonium acetate extractable K)
Calcium - in both plant tissues and soil (ammonium acetate extractable Ca)
Magnesium - in both plant tissues and soil (ammonium acetate extractable Mg)
Manganese - in plant tissues
Boron - in plant tissues
Cadmium - in plant tissues
Chromium - in plant tissues
Copper - in plant tissues

Nickel - in plant tissues
Lead - in plant tissues
Zinc - in plant tissues
Antimony - in plant tissues
Cobalt - in plant tissues
Mercury - in plant tissues
Molybdenum - in plant tissues
Selenium - in plant tissues

To reduce costs, only the first cut of bromegrass was analysed chemically and only selected treatments were analysed for Co, Mo, Hg, Sb and Se. The pH of the soil in all the plots was also measured.

2.2.2 Corn, Elora and Cambridge

The plots for the two corn trials were prepared in the fall of 1972 from an old stand of bromegrass which was plowed under at the Elora Research Station, and from an oat cover crop which was plowed under at the Cambridge site. No phosphate was required on either trials in 1978.

The trial on Conestoga loam was seeded slightly later than recommended due to difficulties getting the sludge hauled when required. Emergence of corn seedlings was adequate to provide uniform stands of the required population after thinning. However, emergence and early growth of the seedlings were relatively poor with the calcium sludge treatments. The Cambridge corn experiment in particular suffered from the dry weather in spite of irrigation to reduce the water deficit.

Measurements and analyses similar to those described in the previous section were carried out. To reduce costs, and because corn grain samples showed few and small differences in chemical composition in previous years, corn grain samples from only two ammonium nitrate rates and the lowest and highest rates of sewage sludges were analyzed chemically. Also, only selected treatments of the corn grain and stover were analysed for Co, Mo, Se, Sb and Hg.

2.3 Summary and Discussion of Results

As mentioned in the introduction, the data upon which the results are based were presented in the original report and are available from the Provincial Lottery Trust Fund Files held by the Pollution Control Branch of the Ministry of the Environment.

As may be seen from Figures 1 to 3, sewage sludge treated with calcium, aluminum or iron to precipitate phosphorus continued to produce as high and frequently higher yields of bromegrass and corn than did ammonium nitrate. From total nitrogen and nitrate concentrations in the crops, there is some indication that nitrogen in the calcium sludge was less available to the crops than that in the aluminum and iron sludges. In 1978, as in 1976 and 1977, less of the nitrogen in the calcium sludge was in the ammonium form when it was applied.

Phosphorus added in the calcium sludge was much more effective than phosphorus in the other sludges in raising the sodium bicarbonate soluble soil phosphorus level. The crops grown did not appear, however, to be sensitive to the differences in extractable soil phosphorus content, probably because the concentrations in the soils and crops were above the level at which response is expected.

As in previous years, soil pH and extractable soil calcium increased with additions of the calcium sludge. The iron sludge at the high rates lowered the soil pH, probably because of the lower calcium and magnesium contents in the sludge. However, because of the soil buffer capacity, the increase in soil pH with the calcium sludge and the decrease caused by the iron sludge has not varied appreciably from one year to the next.

Cadmium, copper, nickel, zinc and molybdenum concentrations in bromegrass and corn stover were increased by high rates of sewage sludge application. Cadmium, copper and zinc concentrations in bromegrass and copper concentration in corn stover were increased to a lesser extent by application of ammonium nitrate. There was some evidence for increased concentrations of nickel and zinc in corn grain with high rates of application of sludges with high content of these metals.

Cadmium and zinc concentrations in corn stover at both sites appear to have increased over the six-year period with high rates of application of the aluminum and iron sludges. The effects on cadmium and zinc concentrations in bromegrass were much smaller. The application in 1976 and 1977 of calcium sludge containing a high level of nickel resulted in increased nickel concentrations in bromegrass and corn stover. The

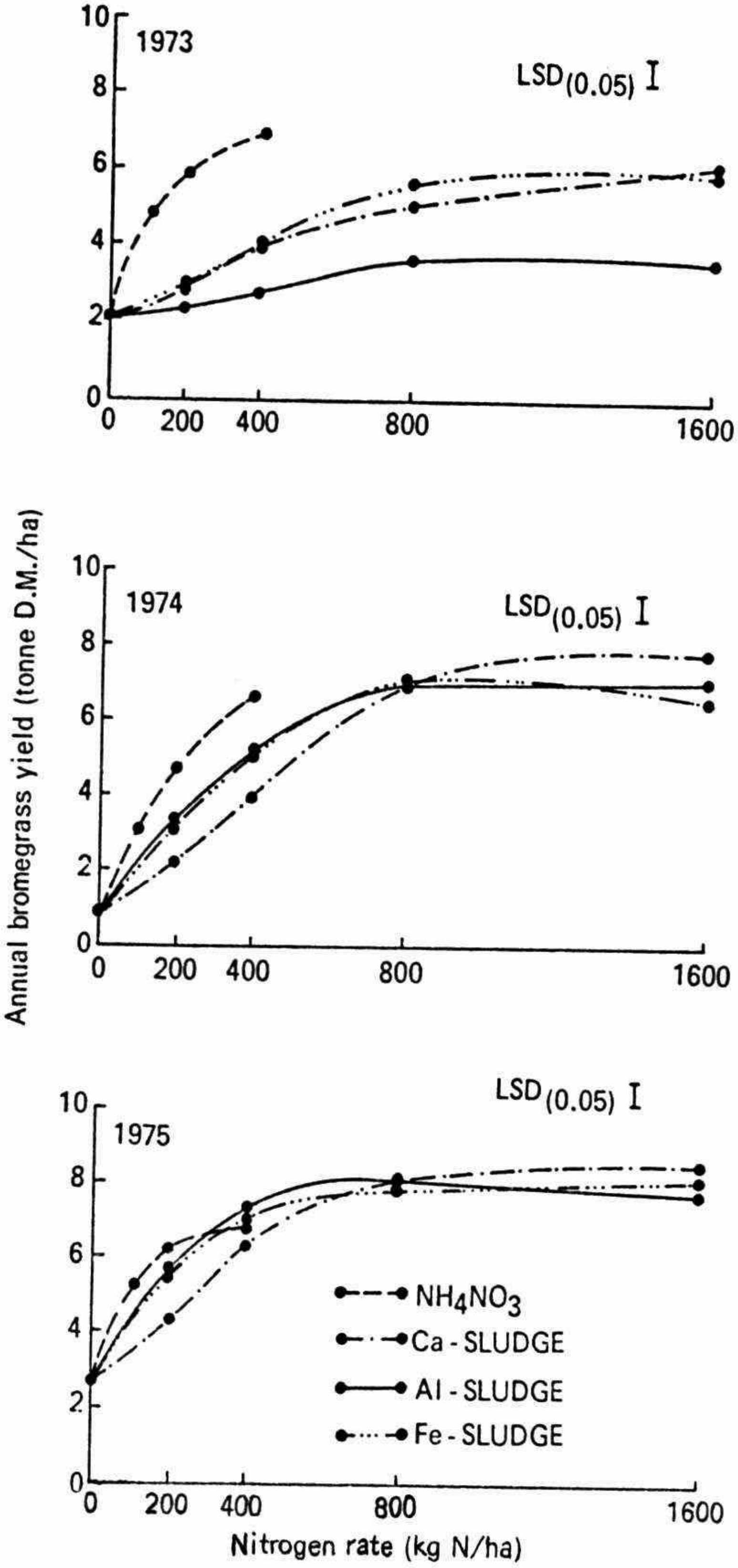

FIGURE 1. THE EFFECT OF RATE AND SOURCE OF N ON BROMEGRASS YIELD

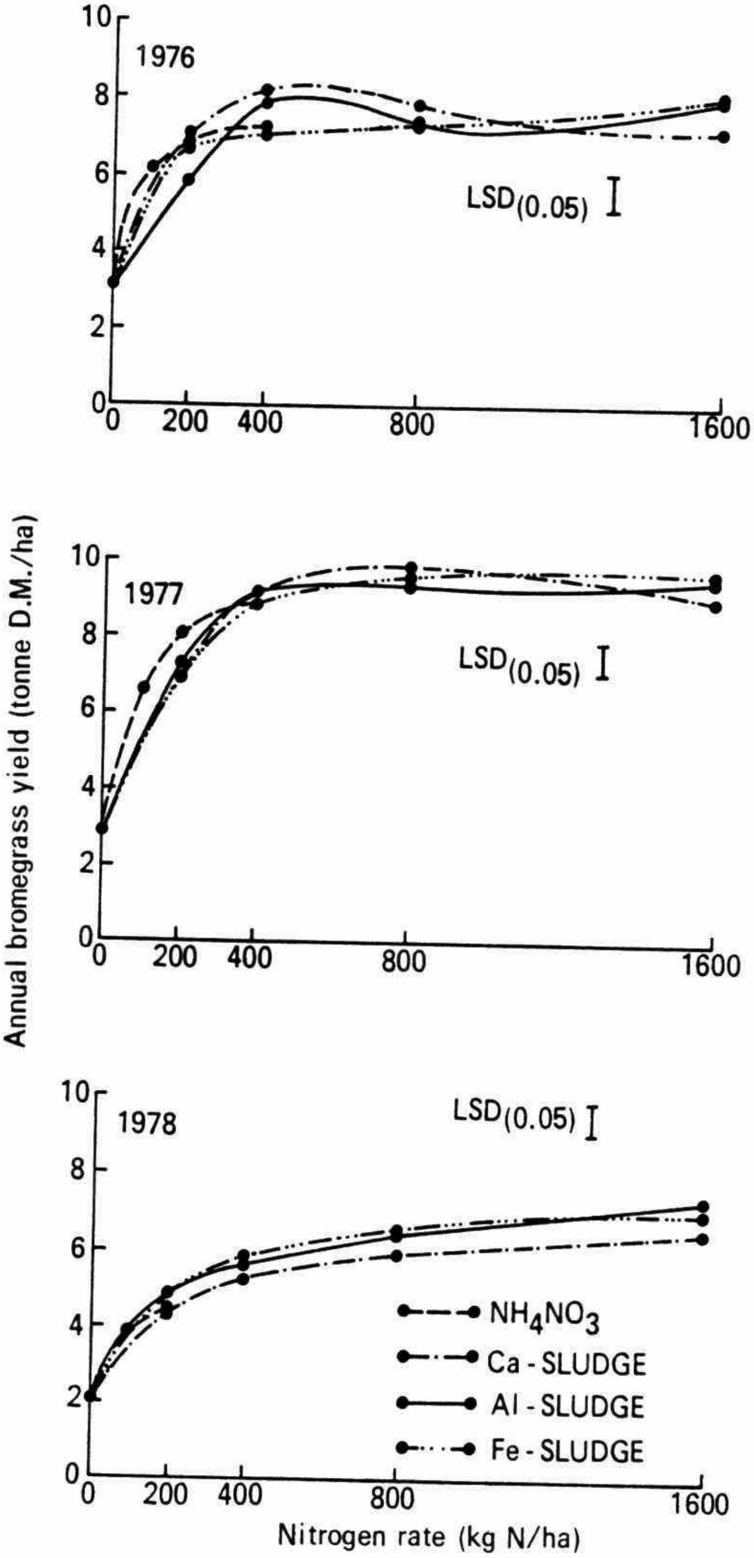

FIGURE 1. (CONT'D)

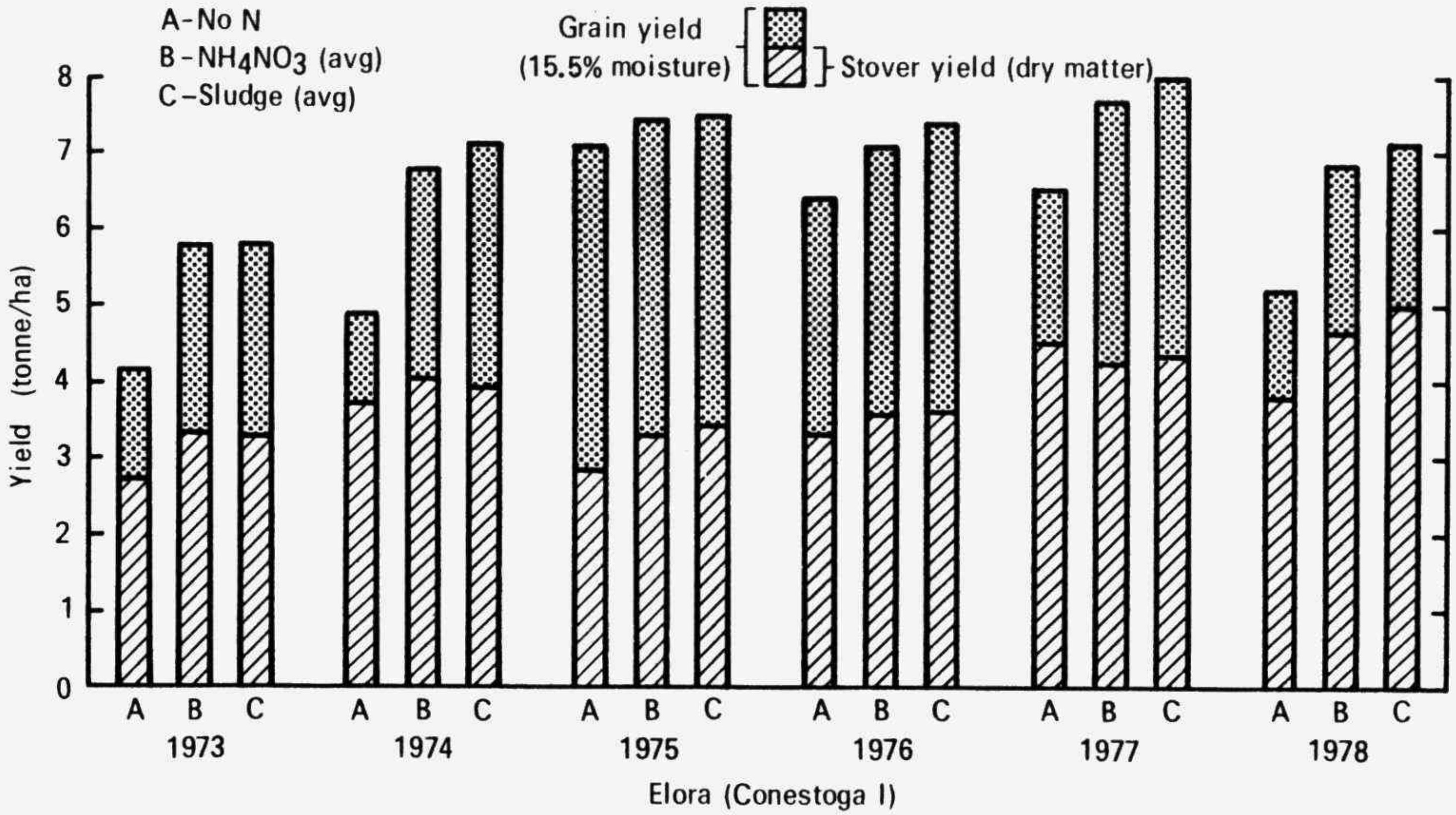

FIGURE 2. EFFECT OF NITROGEN SOURCE ON YIELD OF CORN GRAIN AND STOVER, ELORA

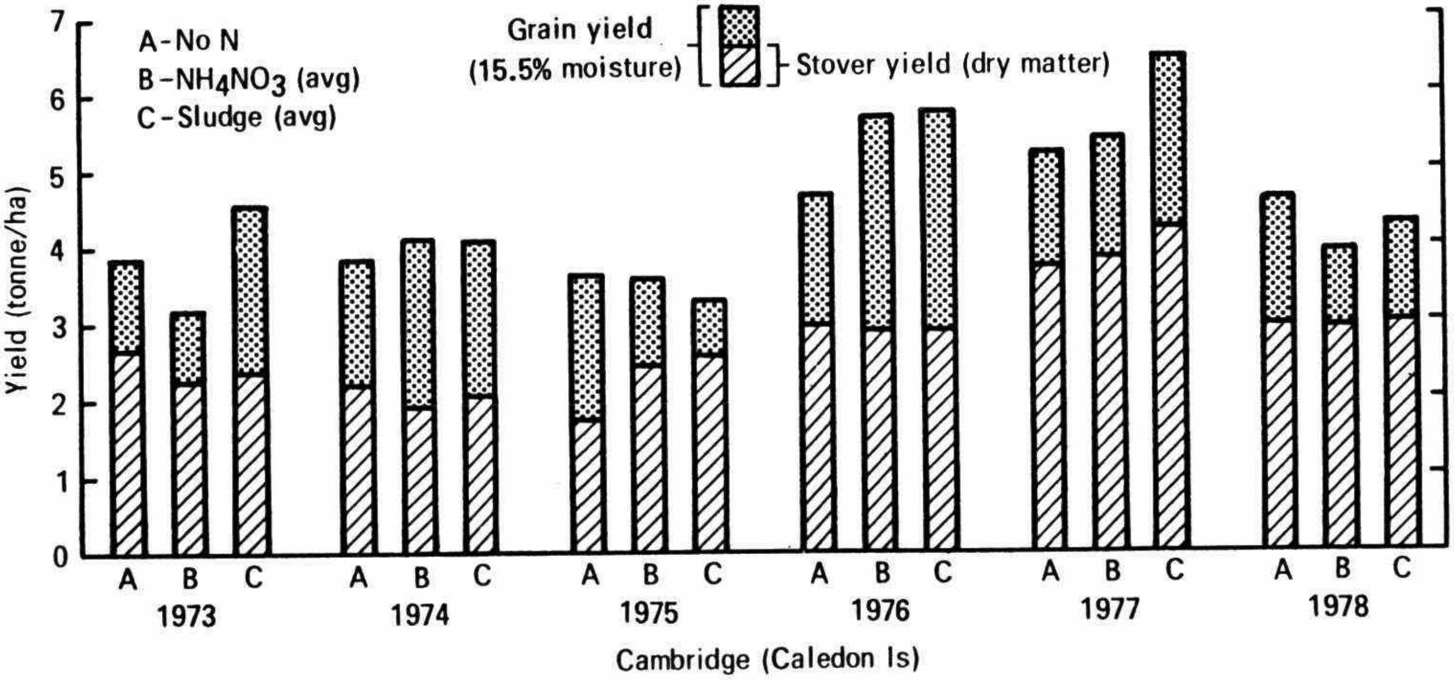

FIGURE 3. EFFECT OF NITROGEN SOURCE ON YIELD OF CORN GRAIN AND STOVER, CAMBRIDGE

calcium sludge was not reapplied on the bromegrass in 1978 and another source of calcium sludge was used on the corn trials, but the residual effect was strong enough to maintain elevated nickel concentrations.

Chromium concentration was increased in corn stover when high rates of the aluminum sludge were applied. The effects of sludge application on lead concentrations in the crops were negligible.

Antimony, boron, cobalt, mercury and selenium concentrations in the crops were not affected by treatment.

3 GREENHOUSE EXPERIMENT

3.1 Introduction

The experiments on the growth of ryegrass under greenhouse conditions are complementary to the field studies and, besides measuring the effect of continued application of sludge on plant growth, they are designed to study more closely the uptake of heavy metal ions present in treated sewage. Sludges used, therefore, were chosen for their high metal content.

The ryegrass was grown in pots containing approximately 2.5 kg of a Grimsby sandy loam soil. At the start of experiments in 1974/75 nine sludges were used; this number was reduced to six after five crops had been grown. This section summarizes results obtained from the twelfth, thirteenth and fourteenth crops. The earlier crops (1 to 11) have been described previously in Volumes III to VI of the project. It should be noted that the soil samples were not changed from crop to crop allowing, thereby, the cumulative effects of sewage sludge application to be followed.

3.2 Past and Present Experimental Details

In the first five crops nine Ontario sludges were applied before seeding of each crop, at rates corresponding to application of 200, 800, and 1600 kg N/ha. One set received 1600 kg N/ha from sludge before the first crop only and none thereafter. After the fifth crop was harvested the pH levels of the soils were adjusted to approximately 6.5 by the application, if necessary, of lime.

Prior to planting the sixth crop, three of the nine sludges were dropped from the experiment. The six sludges retained were added to only half the pots in each treatment before seeding each crop. To the other half of the pots in each treatment, no further sludge applications were made. Six more crops of ryegrass were grown (6th to 11th) before the present experiments.

To reduce salinity problems, the pots were leached following the third, fifth, seventh, ninth and eleventh applications of sludge. Only small proportions of most metals added were removed in the leachates, although losses of the major nutrients such as N, K, Mg and Ca were appreciable in some cases.

For crops 12, 13 and 14 six digested sewage sludges were used, and the sources, together with a brief assessment of the metal-ion content, are summarized below:

Source	Metal Content
Aurora	highest in Na, Al high in Cr, B, Ca
Midland	highest in Ni high in Fe, Co
Sarnia	by far the most polluted sludge highest in Mg, Fe, Mn, Pb, Se, Sb high in Zn, Cd, Hg, Co
Guelph	highest in Cd, Mo high in Pb
Fergus	the second most polluted sludge highest in Cu, Zn, Cr, B high in Mg, Na, Ni
North Toronto	highest in Hg high in Mo, Co

The crop management schedule adopted for this set of experiments is summarized below; it should be noted that only the thirteenth crop was leached.

Operation	12th crop	13th crop	14th crop
Sludge application completed	April 20	July 12	October 12
Leaching completed	-	July 16	-
Potassium chloride added to all treatments	100 kg K/ha May 8	100 kg K/ha August 1	100 kg K/ha November 3
Ammonium nitrate added to check pots, those receiving only one sludge application, and those receiving sludge application for the first five crops only	50 kg N/ha May 8 May 19 May 29 June 5	50 kg N/ha August 1 August 11 August 24 August 30	50 kg N/ha November 3 November 10 November 17 November 28
Ryegrass seeded	May 8	August 1	November 3
Ryegrass harvested	June 19	September 8	December 11
Lime added to treatments requiring it	April 20	July 25*	-

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*0.03 % polyvinyl alcohol added to all pots to improve soil aggregation.

By the end of the fourteenth crop the Aurora treatments were significant in that they had had the highest loading of chromium; the Midland treatments had had the highest loadings of nickel and boron; the Sarnia treatments had had the highest loadings of zinc, manganese and lead; the Guelph treatments had had the highest loading of cadmium; and the Fergus treatments had had the highest loading of copper.

3.3 Summary and Discussion of Results

Continued applications of sludges resulted in yields of ryegrass which, in most cases, were as high as or higher than yields obtained from treatments where sludge had not been applied after the fifth crop. Yields were very low with continued high rates of application of the Fergus sludge. This is believed to have been due to copper toxicity, because yields returned to nearly average levels after sludge application ceased.

Continued applications of sludges low in cadmium decreased cadmium concentrations in the ryegrass compared to the control. In contrast, the Guelph and Sarnia sludges were both high in cadmium but, as is shown in Figure 4, they exhibited different behaviour in plant uptake of the metal. The Guelph sludge increased the cadmium concentration in the ryegrass less when it was added before each crop than in those treatments in which sludge application had ceased after the fifth crop. The Sarnia sludge showed an opposite effect. Higher cadmium concentration was found in the ryegrass treatments to which sludge had been reapplied before each crop than in those cases where sludge application had terminated after the fifth crop. Although the Guelph and Sarnia sludges supplied approximately the same total amount of cadmium over the years, the cadmium concentration in the ryegrass was at least twice as high with the Guelph as with the Sarnia sludge.

Zinc concentrations were quite high in ryegrass receiving several of the sludges and, as may be seen from Figure 5, the zinc concentration decreased after sludge application was stopped. With the Sarnia sludge, which was high in zinc content, the concentration of zinc in ryegrass increased with continued cropping, but this trend was not apparent with sludges low in zinc.

Copper concentration in ryegrass was increased markedly by the Fergus sludge, but omitting sludge application after the fifth crop reduced the copper, nickel and zinc concentrations in succeeding crops.

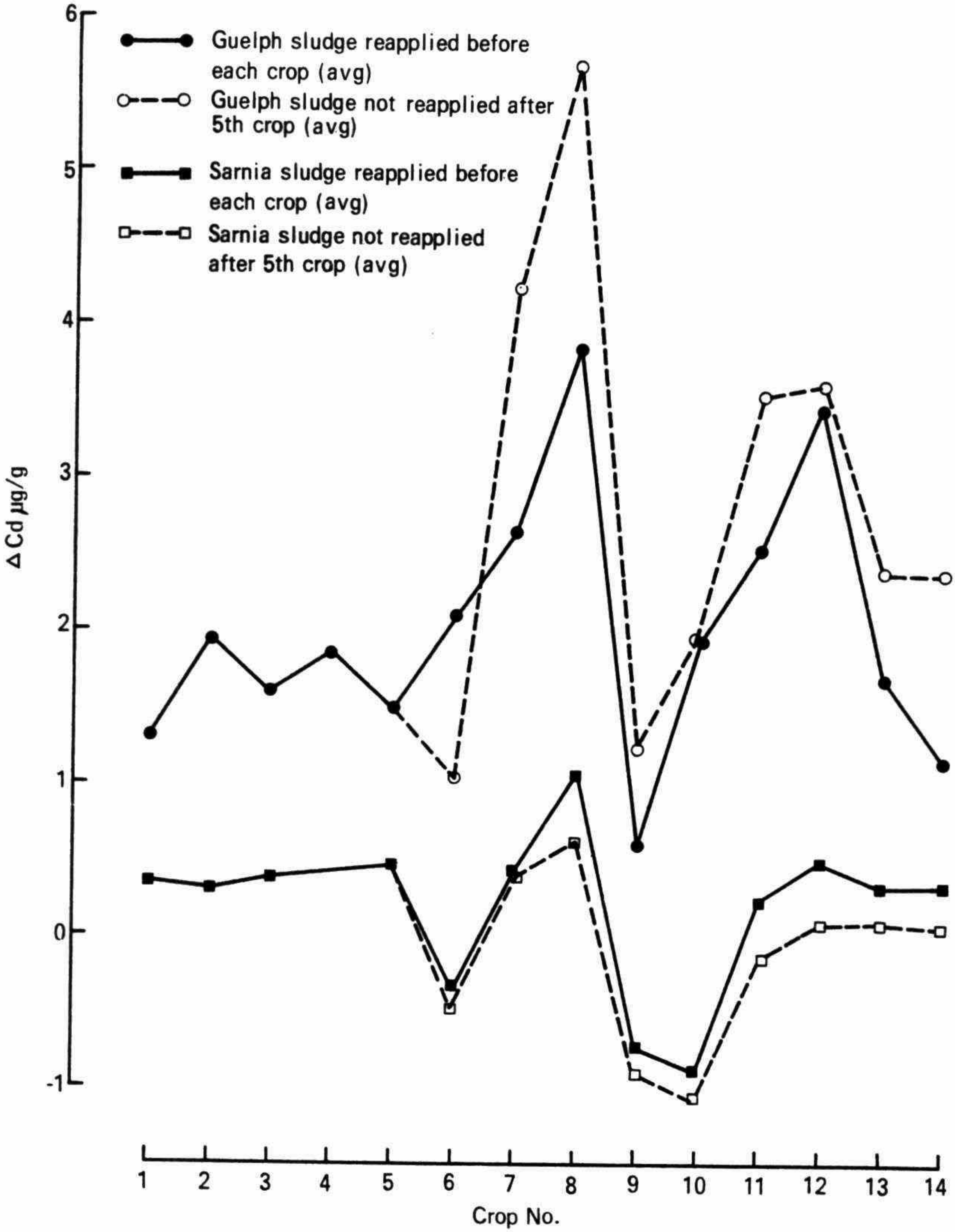

FIGURE 4. CADMIUM CONCENTRATION IN RYEGRASS (shown as deviation from NH_4NO_3 treatment, ΔCd ppm) FOLLOWING DIFFERENT SLUDGE TREATMENTS

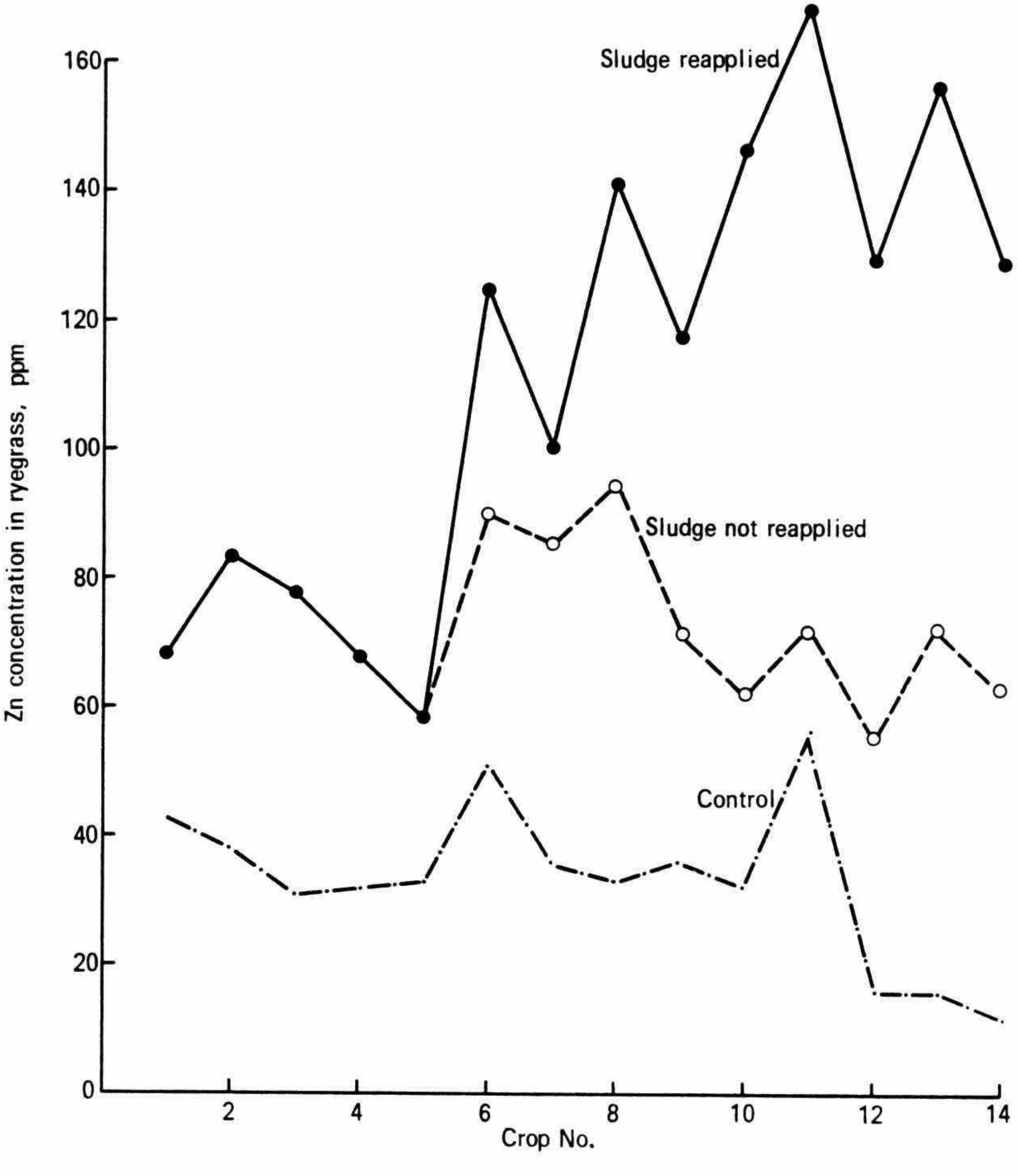

FIGURE 5. ZINC CONCENTRATION IN RYEGRASS. The results are the averages of five sludges (Aurora, Midland, Sarnia, Guelph, North Toronto) and three rates of application.

Nickel concentrations were high in ryegrass receiving the Midland sludge, but did not appear to have affected yield.

Lead, chromium, antimony, mercury and selenium concentrations in the ryegrass were, in general, not affected by treatment. Terminating sludge application appears to have reduced the cobalt concentration in the ryegrass. Molybdenum concentrations were slightly higher where the Midland and Guelph sludges were applied.

It is apparent that metal concentrations found in the ryegrass frequently did not correspond to the amounts of metals ions added in the sludges. This may indicate that metals in different sludges differ in their availability, either because they are in a different chemical form or because their uptake is influenced by other factors which differ from one sludge to another.

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* Research Reports may be obtained from Training and Technology Transfer Division (Water), Environmental Protection Service, Environment Canada, Ottawa, Ontario K1A 1C8, or Ontario Ministry of the Environment, Pollution Control Branch, 135 St. Clair Avenue West, Toronto, Ontario M4V 1P5.

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